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SCFA LEAD LAB TECHNICAL ASSISTANCE REVIEW
OF
SLAC GROUND WATER PLUMES

SCFA TECHNICAL ASSISTANCE REQUEST #82
STANFORD LINEAR ACCELERATOR CENTER
APRIL 5-6, 2001

LBNL-47831

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I. EXECUTIVE SUMMARY

On April 5-6, 2001 a technical assistance team (TAT) met with the Stanford Linear Accelerator Center (SLAC) environmental project leaders and the DOE Oakland Project Manager at SLAC to evaluate ground water plumes at three distinct locations within SLAC. The original technical assistance (TA) request asked only for a review of technologies that were being implemented at the Former Solvent Underground Storage Tank (FSUST) site. However, before the TAT arrived at the site, the TA requester, Jay Tomlin, asked the TAT also to evaluate the ground water plumes in the Plating Shop Area (PSA) and the Former Hazardous Waste Storage Area (FHWSA) since the plumes were similar in nature, and remediation alternatives for the latter two sites had not yet been fully considered. The TAT agreed to evaluate all three plumes. The TAT was comprised of leading technical and regulatory experts from around the country and was assembled by SCFA's Lead Lab in response to a technical assistance request from Jay Tomlin, Project Manager for SLAC at DOE Oakland (Technical Assistance Request: SCFA TA #82, see Appendix B). A list of the TAT members, and names and contact information for all meeting participants is in Appendix A.

To familiarize the TAT with the SLAC ground water plume issues, the DOE Project Manager and SLAC project leaders gave a presentation outlining the site geology, contaminant hydrogeology, land-use issues, stakeholder concerns, regulatory requirements, plume characterization efforts, and remedial options considered for the FSUST site. Time for clarification and questions between the TAT and the site team was integrated into the presentation schedule. In the afternoon of the first day, the site team took the TAT on a tour of the three sites being evaluated. Following the tour, the TAT and site team met to discuss issues they had gleaned from the presentations and tours. On the morning of the second day, the TAT met separately and further discussed its understanding of the issues, and then reconvened with the site team to ask clarifying questions and verify that the TAT had identified all critical issues. The TAT then met independently to consider issues critical to analysis of the ground water contamination plumes at the three sites. The critical issues that the TAT identified included:

<u>Critical Issues</u>

1. Cleanup Drivers
    - 2003 scheduled completion of site characterization and remedial action implementation
    - 2004 transition to long-term-stewardship with a five-year review
    - 2012 current property lease expires
    - Voluntary cleanup - no regulatory imposed MCLs
    - Restore the SLAC site to unrestricted land use levels
    - San Francisquito Creek is sensitive habitat (endangered species and steel head trout spawning grounds)
    - Contamination should not reach the LINAC trench
    - Regional Water Quality Control Board considers the ground water a beneficial use source unless formally dedesignated

2. Overall Environmental Issues

- Slow/low ground water flow
- Ground water flow has shifted direction since construction of the linear accelerator trench
- Low permeability materials
- Fractures are not a major transport feature
- Contamination migration is low both horizontal and vertical
- Ground water is shallow (2 to 35 ft bgs)
- Current and future site activities might affect cleanup

3. FSUST Site

- Contaminated to a depth of 2-30 ft
- Ground water flow direction uncertain (has shifted over time but is stable now)
- Ground water contaminant migration may gain speed as the plume reaches a steeper gradient
- Subsurface biological degradation of the contaminants is evident
- Current and future site activities might affect restoration
- Building 35 footprint sits over part of the plume

4. PSA Site

- May have multiple plumes
- Underground utilities and surface structures limit restoration activities
- A number of building footprints sit over parts of the plume(s)

5. FHWSA Site

- Near site boundary
- Two main hot spots, multiple plumes possible
- Ground water flow shift varies across the site
- Building 15 footprint may sit over part of the plume

Following identification of the critical issues, the TAT discussed characterization data and the hydrogeologic conceptual model for the overall site and the three plumes being considered. Based on this discussion, the TAT strongly recommended that the site develop a comprehensive hydrogeologic conceptual model for the affected area (and integrate the conceptual models for each one of the plumes being considered into that overall conceptual model (see Section III)). The TAT believes that the site team has the necessary data and information to construct such a model and that the project leaders for each of the three plumes already have a good basic idea of the conceptual model for their sites. Development of this model can be accomplished by applying enhanced data analysis, interpretation, and visualization tools to the existing database and the data to be collected in the future. The TAT feels that a comprehensive model of the site will help the site team make future remedial and stewardship decisions. The model will also aid in communicating with, and acceptance of, remedial and stewardship decisions by stakeholders and regulators. In addition to this fundamental recommendation, the TAT also has the following site-specific recommendations:

FSUST

- The TAT supports both the comprehensive alternative remedial technology analysis done by SLAC, and the recommendation to use hydraulic control at this site.
- Consider long-term land use needs during remedy implementation.
- Make stakeholders aware that a new fueling facility being built downgradient of the FSUST may impact ground water restoration efforts if fuel releases occur.
- Natural attenuation is occurring and will continue to occur. The site should acknowledge monitored natural attenuation (MNA) as part of the remedy, i.e., MNA coupled with hydraulic control.
- Consider adapting any of several low cost and passive enhancements to the remedy e.g., enhanced bioremediation by passive infiltration of electron donors (lactate), reinjection of treated ground water downgradient, and using the excavation area as an extraction well.
- Consider use of the Ribbon NAPL Samplers in high concentration source areas. The RNS could be used to confirm the presence of NAPLs in the source area. The installation of the Ribbon NAPL Sampler can be coupled with well installation activities to minimize costs.

PSA

- Develop a record of events from historical photographs and documents and process knowledge gleaned from reports and interviews of long-time employees at the site.
- Investigate buried former and current process waste transfer lines running from the PSA to the Rinse Water Treatment Plant (RWTP).
- More extensive soil sampling for metals and VOCs is necessary for this site.
- Evaluate chemical fingerprints of ground water in this area to identify connections between different wells and source areas.
- Collect dissolved gas from selected ground water samples to confirm existence of natural biodegradation processes.
- Consider an interim action of pumping and treating the ground water contamination from MW-21. A number of portable systems are available that could be used in this configuration.

FHWSA

- Install an additional monitoring well between MW-33 and MW-59 to better characterize the southern plume.
- Install an additional monitoring well between MW-66 and the LINAC to better characterize the northern plume.
- Field screening for VOCs should be used as additional boreholes and wells are installed. This screening may help determine subsurface locations having high concentrations that signify the presence of DNAPL.
- No additional vadose zone characterization is required. It appears that contamination is primarily limited to the vadose zone. Explicit delineation of source areas is not required to institute passive remediation.
- Consider passive venting as a possible interim remedial action for this site. Passive venting would entail removing the asphalt parking lot and replacing it with gravel, or

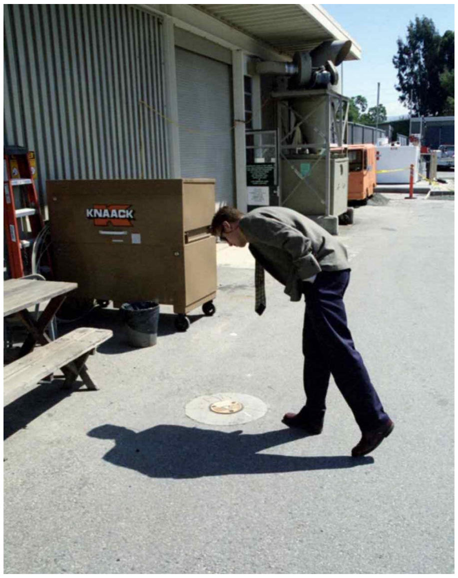
adding landscaping strips that include grass and trees. “Baroballs” should be installed in vents to ensure one-way flow of contaminants outward.

- Consider allowing this site to serve as a location for pilot studies to support activities at the other two sites. Since this site is not as encumbered by buildings and utilities and SLAC workers, it provides a location to test remedial activities to be implemented at the other sites.

The TAT came to a consensus on the following summary recommendations:

- Develop a hydrogeologic/contaminant transport conceptual model of the site. This conceptual model needs to flow hierarchically into detailed models for specific sites paying attention to issues of scale.
- Develop existing data more fully with two-dimensional and three-dimensional visualization of contaminants (in house) for increased in-house data management and interpretation.
- Re-evaluate the site-monitoring program for efficiencies and critical data, e.g., increased frequency of water level analyses and targeting indicator contaminant species to increase sampling frequency of some wells without increasing sampling costs overall.

II. ISSUE ANALYSIS



Based on presentations and discussions with SLAC technical personnel, the TAT identified a number of critical issues that help define and constrain the restoration activities at the three sites addressed in this study. This section presents the critical issues identified by the TAT and brief overviews of how these issues might be important in on-going and future restoration activities.

The TAT team met with the SLAC environmental project leaders on April 5, 2001. The SLAC project leaders presented information regarding the subsurface restoration of three contaminated sites at SLAC: the FSUST, the PSA, and the FHWSA. The SLAC project leaders also took the TAT on a physical tour of all three sites.

Presentation topics included future land use issues, current drivers for the cleanup activities, stakeholder issues and concerns, regulatory requirements, site histories, characterization activities, geology, hydrogeology, contaminant flow and transport, and restoration alternatives and studies for both the individual sites and for the SLAC complex.

The critical issues identified by the TAT are divided into overall issues (issues that are common to all sites) and site-specific issues. The focus of the first section of this report is identifying issues common to all of the SLAC sites reviewed, with secondary consideration of site-specific issues. The following sections focus on the FSUST, the (PSA), and the FHWSA, and describe recommendations for future site-specific activities.

A. Overall Issues

A number of issues are common to the three sites addressed in this study including cleanup drivers such as stakeholders' concerns, regulations, and the affected environment (i.e., site geology and hydrogeology).

Cleanup Drivers

DOE-OAK has established a cleanup deadline of 2003. At this point, DOE would like to transition the sites from active restoration to long-term-stewardship status, which essentially means that ongoing costs will be for operation and maintenance of in-place remedies. Under long-term-stewardship, the restoration sites will undergo five-year reviews to determine if the in-place remedies are performing as expected or to determine if operational changes are appropriate. The review will also assess new technologies to reach long-term goals. The 2003 deadline is arbitrary in the sense that there are no outside requirements for beginning or completing active restoration at this time. In addition, the current 50-year DOE lease of the SLAC complex from Stanford will expire in 2012. It is expected that a new multi-year lease will be negotiated at that time. SLAC and DOE personnel expect that site contamination may be an issue in this negotiation.

The restoration activities at SLAC are voluntary. Cleanup levels are determined by stakeholder desire to restore the sites to unrestricted use (i.e., residential standards). A deed restriction on the use of groundwater as a drinking water source is acceptable to Stanford University.

Stanford, the property owner, also has indicated that any ground water contamination should be intercepted before it reaches the ground water capture trench underneath the linear accelerator (LINAC) tunnel. All stakeholders have indicated a preference for active restoration. Stanford specifically requested that SLAC investigate the possibility of bioremediation.

The Regional Water Quality Control Board (RWQCB) supports restoration of the site to unrestricted land use levels. Ground water at SLAC is unsuitable for municipal and domestic supply because of natural background water quality (high total dissolved solids (TDS), sulfate and chloride content, and low yields. Currently there is no RWQCB order in place for cleaning up the site; however there is a 1985 RWQCB board order to investigate the FSUST area. In addition, the Department of Toxic Substance Control may have some interest or jurisdiction in site cleanup activities; however, the Department is not involved at this time.

One of the important requirements for restoration issues at SLAC is the ability to clearly present complex technical analysis and decisions to stakeholders and other non-technical parties. In addition, SLAC needs to demonstrate active restoration to the site owner and other stakeholders. It appeared to the TAT that DOE and SLAC significantly under estimated the scope of work to be performed at SLAC. Their initial focus was on PCB problems and little attention was given to the groundwater problems. There was a belief that the plumes were not migrating, so not much work would need to be done. As the parties became more aware of the regulatory and stakeholder concerns, and the amount of work required, the budgets have increased. Although the SLAC budget is relatively small, it has increased from approximately $1M in 1998 to $2.6M in 2002. DOE wants to implement the solutions that will result in the lowest life-cycle costs for the project. DOE is willing to spend more money upfront, if it will reduce out-year costs (e.g., stewardship costs).

In addition to the above requirements, the San Francisquito Creek drainage south of SLAC is sensitive habitat that supports endangered species and steel head trout spawning beds. Storm water runoff from SLAC and drainage from the capture trench below the LINAC drains into this creek.

<u>Overarching Environmental Issues</u>

Thick bedrock deposits of siltstone to silty-sandstone underlay the sites. Well-cemented sandstone beds are interlayered with siltstones and sandstones that are more poorly cemented and can be drilled with an auger. There is little unconsolidated overburden overlying bedrock at the sites. The shallow bedrock at SLAC chiefly belongs to the Miocene Ladera formation and is up to 2000 feet thick below SLAC bases on regional information.

Depth to ground water varies from about 2 to 35 feet below ground surface. Grading activities during the construction of SLAC removed significant material that has affected depth to groundwater. In addition, the subdrainage system of the LINAC appears to exert a controlling influence on ground water flow on both the north and south sides of the accelerator. Water quality is poor with TDS ranging from 3,500 to 9,000 mg/L. Well yield is low, in the 0.04 gpm range, for the typical monitoring wells at SLAC.

Ground water flow is slow, primarily due to the low hydraulic conductivity of the Ladera Formation. Low conductivity measurements were taken during various site characterization activities, with values raging from 1 x 10^{-7} to 1 x 10^{-5} cm/s. One other indication of the low permeability and slow ground water movement is the small amount of infiltration along the LINAC capture trench, approximately 2 gpm along 1,500 ft of trench that is about 65 ft below the ground surface.

There is significant evidence of fractures in the bedrock beneath the site, but pump tests, existing contaminant plumes, and other measurements suggest that fractures are not large-scale transport features. Quantitative fracture studies at SLAC have been unable to relate fracture density and distribution to ground water flow. The TAT believes that the SLAC complex can be conceptually treated as an equivalent porous medium with minimal heterogeneity.

III. DEVELOPMENT OF A CONCEPTUAL MODEL

Creating an accurate site conceptual model is the most important element of any environmental remediation project. All remedial decisions and strategies should be based on a solid understanding of the geological and hydrological features that affect contaminant transport at the site. The geologic, lithologic and hydrologic features at a site control where and how the contaminants will be transported through the subsurface. Understanding ground water flow patterns at the site is critical to predicting where the contaminants will appear and to defend decision-making.

The characterization team at SLAC has done a remarkable job in obtaining most if not all of the required information to develop a defensible conceptual model. The TAT commends the site on their efforts. Earlier efforts to develop a comprehensive conceptual model were abandoned in favor of individual efforts for each of the waste units (hydrological review). The TAT recommends that SLAC allocate additional resources to update and strengthen the comprehensive site conceptual model for contaminant flow and transport at the site and support ongoing project work by adding site specific information to that model for each of the individual sites.

A. Ground Water Hydrology

The primary factor controlling ground water flow at SLAC appears to be advective flow. The ground water flow rate at SLAC is extremely slow. This is dramatically demonstrated by the very low amounts of discharge, on the order of only a few gallons per minute, from a 1500 ft segment of the LINAC.

A key issue remaining for the conceptual model development and remedial design-making is to determine whether the flow at the site is consistent with porous media flow or by fracture flow at the scale appropriate for ground water flow and transport modeling. In most of the documentation provided to the TAT, it was implied that fracture hydraulic conductivity is a primary flow mechanism at the site.

A significant level of effort has been directed toward measuring hydraulic conductivity and mapping fractures at the site on both an outcrop and borehole scale. These activities are documented in several reports including the site characterization report for the FSUST site (SLAC, 1998). Fracture flow at the outcrop scale is suggested by several observations. Ground water was observed seeping from fractures during borehole televiewer imaging at the FSUST site. Values of vertical hydraulic conductivity measured made in unfractured core material measured in the laboratory range from 3.16×10^{-7} to 2.55×10^{-5} cm/s with an average value of 5.4×10^{-6} cm/s (SLAC, 1998). Measured horizontal hydraulic conductivity values are similar, with an average value of 3.2×10^{-6} cm/s (SLAC, 1998). Hydraulic communication between wells spaced a few tens of feet apart was observed during two pumping tests, however, the hydraulic conductivity estimates are still on the order of 10^{-5} cm/s similar to those measured in core material. Data collected during a constant-head pumping test were interpreted using several different methods. This was necessary due to difficulties in evaluating results because of very low discharge rates in the tested wells. Calculated hydraulic conductivities ranged from 4.7×10^{-7} to 1.1×10^{-4} cm/s. The interpretation of the pump test data suggested that the higher values were more representative of flow at the site, and concluded that the "ground water movement in the FSUST area is probably dominated by flow through fractures and the fracture hydraulic conductivity may be approached on the basis of individual fractures" (SLAC, 1998).

The TAT does not feel that fracture flow is necessarily a dominant mechanism at the scale appropriate for flow and transport modeling. These measurements are consistent with the conceptual model of advective flow being limited primarily to the low permeability siltstone matrix. In this model, fractures function mainly as local storage rather than facilitating advective flow, except at small scales. As such, contaminant transport appears to be via porous medium flow (as opposed to fracture flow that might result in preferential flow directions and faster transport rates). Consequently, the data collected to date suggest that simple analytical or numerical models can represent contaminant transport due to the relative homogeneity of the aquifer.

The TAT suggests that a simple, one-dimensional flow model assuming porous media flow without fracture flow should be tested. If the model results are consistent with observed values, then fracture flow at this scale is a secondary effect probably due to the lack of interconnectivity in the fractures at the field scale. If the observations are consistent with porous media flow, this would greatly simplify calculation of particle tracking and travel time curves that are often critical mechanisms for communicating with decision-makers and stakeholders.

B. Contaminant Fate & Transport

The primary factor controlling transport of contaminants appears to be advective flow with fate processes such as degradation, sorption, and volatilization being of secondary importance. It is likely that the maximum velocity of contaminants in the subsurface is that of the ground water, and the rate of contaminant migration may be retarded due to interaction with the solid aquifer matrix. In the case of SLAC, the extent to which contaminants are retarded is not clear, but it was mentioned that the organic carbon content in the soil and bedrock (an effective sorber for many organic contaminants) is fairly low. This would suggest that retardation may be minimal, but contaminant migration is nevertheless limited to the extremely slow rate of ground water flow.

The effect of dispersion on contaminant transport is difficult to assess due to the relative lack of migration at the SLAC sites. Given the slow rates of advection, diffusion may actually be more important than dispersion at the scale of the plumes for determining the extent of spreading. Also, in the vicinity of the LINAC, the spreading of the plumes is affected by the highly variable direction of the water table gradient. This factor will be discussed for each of the three SLAC sites below. An additional process that may affect transport at the sites is volatilization of the contaminants. Because of the relatively shallow depth to water and the volatility of many of the primary contaminants, this process could be significant. However, due to the presence of asphalt at the three sites, volatilization may currently be largely inhibited. Were the asphalt removed, volatilization might affect contaminant fate.

The expected primary degradation mechanism for the organic contaminants at SLAC is biodegradation. One exception to this is 1,1,1-trichloroethane (TCA), which can be abiotically degraded to acetic acid and DCE. Nonchlorinated organics are typically oxidized, with fastest degradation rates occurring in the presence of oxygen, and decreased degradation under increasingly reducing conditions. In the case of the chlorinated organics that are generally more susceptible to reduction than oxidation, biodegradation requires the presence of an oxidizable organic compound to serve as an electron donor. Thus, degradation of the chlorinated compounds is generally more significant when nonchlorinated organics are also present. These oxidizable organics can be naturally occurring, but are often co-contaminants.

C. Ground Water Monitoring

The TAT suggests that monitoring of key parameters including water levels and contaminant concentrations should be done on a regular, scheduled basis. At least initially, water levels should be measured in all of the site wells on a monthly basis to establish seasonal variations. Key ground water wells should be identified for routine quarterly sampling to build a robust database. For well-characterized wells, targeting indicator species for routine analysis, and running the entire suite of contaminants only on a yearly basis can reduce monitoring costs. Reduced monitoring should be used in wells where monitoring data are available for at least several quarters and during which time contaminant concentrations have remained relatively stable.

Ribbon NAPL samplers (NAPL FLUTE) could be used during site investigation activities to confirm presence of DNAPL in high concentration source areas. Ribbon NAPL samplers could be deployed in the wells immediately after drilling to delineate the presence of NAPLs intersecting the borehole wall. The sampler is simply a ribbon on the outer surface of a nylon liner that is extended down into the well and pressurized to form a seal against the wall. If NAPL is present, it interacts with a dye in the ribbon producing an obvious color change that reveals the location of NAPL when the liner is removed from the well (select “Innovative DNAPL Characterization Technologies” at http:www.envnet.org/scfa/prodlines/factsheets.htm for more information). One consideration when using this approach is that mud rotary drilling would probably interfere with the results because of the presence of mud on the wall and in the formation, displacing subsurface fluids. If successfully deployed, the samplers could reveal critical information concerning the distribution of NAPLs in the source area.

D. Data Integration

The TAT found that while a significant amount of excellent, quality-assured data has been collected at the site, it has not been fully utilized to effectively communicate conditions at the site to stakeholders. The TAT believes that existing data can be integrated and used to evaluate the relative risk of the subsurface contamination, and to convince the stakeholders that site personnel have an adequate understanding of the relevant issues. The site conceptual model is the initial product that would benefit from such data integration. SLAC personnel report that development and maintenance of a conceptual model has not been a focus of their efforts for several years. Improvements to the conceptual model would include:

- More detailed geologic cross-sections. Increased understanding of the stratigraphy and how it controls flow of both water and contaminants
- More detailed conceptualization of the distribution of contaminants, and
- A better description of the hydrology and how it relates to the fate and transport of contaminants.

Additional focus on the above elements would help the site understand how each of these basic conceptualizations controls ground water contaminant migration. This understanding will in turn affect the design and implementation of remedial options in complex scientific, regulatory, political, and financial environments.

Data visualization tools linked to the database would provide a much more robust conceptual model and would prepare the site for application of computational models. These tools are commercially available in packages by vendors such as Rockware, Surfer, Arcview, and others. They provide enhanced geologic maps and cross-sections, contour plots of ground water elevation, contour plots of contaminant distribution, graphs of time series concentrations in individual wells which could then be plotted against parameters such as water level changes, and animations of water level and contamination changes through time.

Interpretation of the site data using these or similar data integration tools would also benefit the site investigation by pointing out data gaps and suggesting priority for additional data needs. These integration tools, when applied to both time-static and time-dependent data, are invaluable in establishing an initial conceptual model and when used in an iterative fashion can continually be used to refine the model. They can then be used to provide boundary conditions, parameters, and initial conditions for computational models, which can be considered the most advanced of the currently available data integration tools.

In summary, the TAT believes that substantial progress can be made toward improving the contaminant hydrogeologic conceptual model of both the overall site and the specific sites under investigation by applying enhanced data analysis, interpretation, and visualization tools to the existing database and to data to be collected in the future. Use of such data integration tools allows the rapid acquisition of answers to questions that would not even be asked in the absence of these tools. Data visualizations can be invaluable in communicating, to all of the stakeholders, the conditions at the site as well as how those conditions effect the remediation and funding decisions under consideration.

IV. FORMER SOLVENT UNDERGROUND STORAGE TANK SITE

The FSUST site is thought to be the most time-critical of the sites because implementation of a proposed remedy is already underway. In order to develop recommendations for the site, the critical issues (both technical and managerial) were considered, unresolved issues were identified, and the remedial alternative analysis was reviewed. These steps are discussed in this section, followed by the recommendations.

A. Critical Issues

The FSUST site is the furthest along of the three sites reviewed, in terms of characterization and remedy selection. A comprehensive analysis of remedial alternatives has been performed, and SLAC is moving forward with the selected remedy of hydraulic containment including pump and treat for source area treatment.

The FSUST site is contaminated with VOCs to a depth of 25-30 ft. The original contamination was the result of a leaking underground storage tank that has been removed. There may be some residual NAPL present near the former site location. The site contamination has produced a dissolved-phase contaminant plume that is approximately 200 ft long. The plume and source area are located in an area with almost flat ground water gradients, and there are some indications that ground water flow directions in this area have shifted direction from a northerly flow to a south-southeast flow between the late 1980s and early 1990s.

The site has been the subject of intensive investigation including taking soil borings, soil vapor measurements, and construction of ground water monitoring wells. These measurement locations bound the plume on the south, west, and north. The east side of the contaminated area and ground water plume lies under an existing plant maintenance building which limits characterization and restoration alternatives. Soil vapor data suggest that the contamination may extend beneath the building. Based on concentrations in MW-4, contamination appears to be limited to the upper 30 ft or so of the aquifer.

Contaminants at the FSUST site include a wide range of volatile organic compounds, both chlorinated and nonchlorinated. Extremely high concentrations of methylene chloride, acetone, and toluene are particularly notable in well VP-1, adjacent to the excavated tank. Trichloroethylene (TCE), 1,1,1-TCA, and 1,1-dichloroethane (DCA), ethylbenzene, and xylenes are also present in this well at concentrations above 1,000 µg/L. Concentrations of all of these compounds were apparently so high that detection limits of other organics were 2,500 µg/L during sampling in 1997. In spite of the high concentrations of several of the contaminants, the plume is remarkably small, extending merely 100 to 150 ft to the south from the tank. The extent of contamination is fairly well characterized except to the east where Building 35 prevents easy sampling access.

During the site visit, the TAT noted that a fueling station is under construction within a few feet of the southern end of the plume. Future site uses, such as refueling, may affect FSUST site restoration.

Although the plume is very small for its age due to the slow ground water flow in the low permeability siltstone matrix, contaminant concentrations have increased for the last several years in MW-7 and MW-5. One factor that may have affected concentrations at MW-7 is an apparent change in the direction of the hydraulic gradient that began in the early 1990s from northward to southward. The data upon which this shift in the gradient is based are fairly limited, so interpretation of the data in light of the shift must be considered tentative. Another factor that may have played a role in contaminant transport during this timeframe is the removal of the solvent tank. Once the tank was removed, the excavation (which extended several feet below the water table) was backfilled with pea gravel. The result is an infiltration gallery that appears to collect storm water from the immediate vicinity. Not only is the chemical signature of water sampled from the backfilled pit very different from the surrounding formation, it is our understanding that the hydraulic head is higher than the formation indicating existence of a downward hydraulic gradient. Radial flow that may result from enhanced recharge at this location could explain increases at both MW-7 and MW-5. This would also explain the timing of the observed changes in what has otherwise been a fairly static plume. (See Table 1 for map showing monitoring well location at the FSUST site.)

It should also be noted that the hydraulic gradient in the vicinity of MW-5 appears to be more toward the east. This might cause contaminants from the area of SVE-1, which has the second highest concentrations at FSUST, to migrate toward MW-5. Both the temporal and the spatial variation of the gradient direction at FSUST may contribute to the lateral spreading of contaminants, although net migration appears to be quite small. The hydraulic gradient appears to steepen as ground water approaches the LINAC suggesting contaminant transport rates might increase. The discharge rate at the LINAC drain outfall indicates flow rates are still quite small even where the gradient is steep.

The ratios of contaminants at various wells, together with redox indicators, provide a strong indication of the biological activity occurring at the site. While very high concentrations of oxidizable organics such as ethylbenzene, toluene, xylene, methylene chloride, and acetone are present at VP-1, they were not detected in MW-7. On the other hand, TCE, which was present at lower concentrations in VP-1 than the oxidizable organics, is above 100 μg/L in MW-7. In addition, the highest iron, lowest sulfate, elevated methane, and elevated alkalinity are present at VP-1. These data indicate significant biodegradation of oxidizable organics in the vicinity of the tank excavation, resulting in a dramatic shift in redox conditions toward strongly reducing conditions. Conditions in the vicinity of the SVE wells are similarly reducing. The degradation of the oxidizable organics and the strongly reducing conditions in these areas provide the appropriate conditions for biodegradation of the chlorinated organics.

The extent to which reductive dechlorination might be occurring is difficult to assess due to the high detection limits for the less chlorinated compounds in VP-1. Nevertheless, the presence of ethene and ethane, albeit at low concentrations, indicates reductive dechlorination is occurring. The ratio of TCE to *cis*-1,2-DCE at MW-7 and the shift to more oxidizing conditions demonstrates that while dechlorination is occurring in the former area of the tank, it is limited by the lack of oxidizable carbon outside that area. Degradation rates of the oxidizable organics are clearly limiting their migration relative to the chlorinated organics. In addition to degradation of TCE, degradation of 1,1,1-TCA is also apparent. Very high concentrations of 1,1-DCA are present in VP-1, so high in fact, that it seems likely it was a primary contaminant. Some may be due to reductive dechlorination of 1,1,1-TCA however. The detection of ethane in VP-1 is a strong indicator of reductive dechlorination of the chlorinated alkanes. The presence of 1,1-DCE in MW-5 and MW-7 suggests abiotic degradation of 1,1,1-TCA is also occurring.

A 1998 report evaluating intrinsic degradation of chlorinated solvents at the FSUST concluded that evidence for biodegradation of the chlorinated organics was limited. This was based largely on a scoring of the evidence following a popular technical protocol. This conclusion probably underestimates the importance of biodegradation of chlorinated organics at the site. In fact, the point total in the table could easily have been as high as 21, indicating "strong evidence of biodegradation", rather than the 14 found in the report. While biodegradation is not sufficient to prevent migration of TCE and 1,1,1-TCA completely, it appears to be impacting their transport to some extent, and transport of the latter seems to be particularly limited due to the additional impact of abiotic degradation.

In summary, the primary mechanism controlling contaminant transport at the FSUST site is the low conductivity aquifer and the corresponding slow ground water flow rates. Migration of the plume of organic contaminants has been extremely slow. Lateral spreading of the plume appears to be affected both by temporal and spatial variations in the direction of the hydraulic gradient. The oxidizable organic contaminants are being dramatically impacted by biodegradation, with their migration apparently prevented. This is facilitating some degree of reductive dechlorination of the chlorinated organics although the extent is difficult to assess with the existing monitoring network.

B. Unresolved Issues

The primary unresolved issue at the FSUST site is common to all of the SLAC sites: a conceptual model would enhance the explanation of contaminant fate and transport at the site. As discussed in detail in section III, development of this model will greatly assist remediation of the site by aiding the design process, facilitating communication with stakeholders, and helping plan for long-term stewardship of the site. Two other issues related to the conceptual model are the lack of an analytical or numerical modeling tool, and uncertainty regarding the hydraulic gradient at the site. While they have a model for siting the containment system, they do not have a model for contaminant fate and transport.

A predictive tool would be a great asset to SLAC as plans for the future are discussed with stakeholders. The TAT believes that contaminant transport is occurring in a relatively homogeneous system at the FSUST. This suggests that an analytical model may be appropriate for simulating transport, but in any case a fairly simple numerical model could be used. The model can be used to design the hydraulic containment system, to communicate expected performance to stakeholders, to evaluate different remediation scenarios, and to make decisions regarding long-term stewardship. Visualization of model results would be a powerful tool for stakeholder communications.

The final unresolved issue is the hydraulic gradient at FSUST. While water levels are being collected quarterly at present, it is believed that the hydraulic gradient shifted by about 180°, but has been stable over the last 10 years. Quarterly data collection may not be sufficient to capture the variability in gradient direction. The extent to which the gradient might be toward the east as one moves away from the LINAC, is also unresolved. This might affect migration of contaminants under Building 35. Reduction of uncertainty regarding the hydraulic gradient would improve both conceptual and analytical or numerical models of the site.

C. Remedial Alternative Analysis

SLAC personnel performed a comprehensive evaluation of remedial alternatives for FSUST. The list of technologies considered was very thorough, with no omissions noted by the TAT. Most importantly, the conclusions of the evaluation were technically sound and the TAT strongly supports the decision to move forward with the selected remedy of hydraulic containment using pump and treat for source area treatment. The TAT had a few comments on the evaluations of specific technologies. To the extent that these comments might impact the final remedy, they are discussed in the Recommendations section below.

- Although permeability is low for vacuum extraction and air sparging, methods to enhance the performance of these technologies are available.
- For impermeable containment technologies (i.e., slurry walls, grout curtains, steel sheet pile walls), it was noted that an additional difficulty would be the high cost associated with installation of such a barrier in the siltstone that comprises the aquifer at SLAC. The TAT also noted that an impermeable barrier would likely require active pumping to control the hydraulic gradient, which would further increase costs.
- With regard to trenches, the TAT believes they may be viable as part of the hydraulic containment proposed for the remedy. Trenches could also be considered for delivery of amendments to the aquifer for in situ treatment of the contaminants.
- The TAT believes the cost estimate for trench installation for containing the entire plume is probably excessive because the scenario considered assumed trenching surrounded the source area.
- For bioremediation, the evaluation identified a concern that toxicity might be a problem in the source area. Toxicity is probably not an issue. In fact, it is clear that oxidizable organics are being degraded to a significant extent in the source area, and that some reductive dechlorination is occurring.
- It was also stated for bioremediation and chemical oxidation that the fractured nature of the aquifer might cause difficulty for amendment addition. In both cases, the low permeability matrix is a legitimate concern for delivery of amendments to the subsurface, but the TAT does not feel that fractures would cause difficulty at the scale of the plume.
- While the TAT strongly supports the remedy selection by SLAC, it may be possible to enhance the remedy by using additional hydraulic strategies, or by coupling it with other technologies as discussed further below. A conceptual model of the site may strengthen stakeholder and regulator acceptance of the remedy.

D. Recommendations

As noted above, the selection of hydraulic control including pump and treat for source area treatment is a technically sound choice given the conditions at the site. In conjunction with this remedy, several additional activities are recommended for consideration to help ensure its success and perhaps even improve remedy performance.

- First, it is recommended that long-term land use be considered while the remedy is being implemented. An immediate example of this is the fueling station currently being built downgradient of the ground water volatile organics plume. All of the stakeholders should be made aware of the possible impact of this facility. Facilities such as this almost always produce petroleum hydrocarbon contamination within a short time of beginning operations. On the one hand, this location might be ideal if the facility is within the hydraulically contained zone at FSUST. On the other hand, the stakeholders should be aware of this possibility so that petroleum hydrocarbon contamination is not mistakenly assigned to the FSUST source area.
- A very important consideration during remedy implementation is the intrinsic biodegradation that is occurring at the FSUST site. As noted in the conceptual model section of this report, the oxidizable organic contaminants are clearly being degraded to the extent that their migration is at least greatly limited if not completely prevented. In addition, some amount of reductive dechlorination of the chlorinated organics is also occurring, although not enough to prevent migration. This intrinsic biodegradation should be included as a major part of the remedy in discussions with stakeholders. It appears that more mass has been and will continue to be removed by this process than by the treatment of extracted ground water. Additional measurements of electron acceptors (O_2, CO_2, CH_4 and daughter products, e.g., *cis*-1,2 DCE and vinyl chloride) will provide all the parameters necessary to verify that natural attenuation is occurring. It is recommended that the remedy be presented as Monitored Natural Attenuation with Hydraulic Containment. The site needs to take more credit for the natural attenuation that has already occurred and the natural attenuation that will most certainly increase as hydraulic containment is implemented.
- Electron donor addition to the source area may also facilitate further biological reductive dechlorination of the chlorinated organics, and should be considered by the site. The electron donor could be added using the excavated area that has been backfilled with pea gravel. Sodium lactate is an electron donor that could easily be used for this purpose (Groundwater Currents, December 2000; or see information available at http://www.wpi.org/initiatives/init/summer00/bioremediate.htm). It is very inexpensive and would be added as a liquid to the gravel-filled "pit". When added at high enough concentrations, it is denser than water and would be expected to sink in the aquifer, allowing treatment deeper than the bottom of the pit. An added benefit of the high concentrations is that they enhance bioavailability of hydrophobic contaminants by acting as a mild surfactant. Small quantities of electron donor could be added initially as an inexpensive, risk-free trial, and larger quantities could be added later if it were beneficial. Some additional comments on this approach in the context of the evaluations of bioremediation that have been performed to date are provided at the end of this section.
- A more aggressive approach that would involve higher cost would be the addition of both an electron donor and electron acceptor. Similar plumes of contaminants in fractured rock environments have been successfully remediated by sparging gaseous nutrients into the source area to encourage co-metabolic oxidation of the solvents (Ground water Currents, December 2000). This has the advantage of not producing toxic daughter

products, e.g., vinyl chloride, but has the disadvantage of requiring more equipment and monitoring, and thus greater expense. It also results in the slower degradation of PCE since it is not attacked directly by the soil bacteria being stimulated. The sparge well could be established in the excavated area and adjusted to minimize stripping of the contaminants. It initially could be operated with air injection alone (if enough electron donor were already present). This approach should only be considered if the passive anaerobic stimulation results in the incomplete reduction of the solvents, and the stakeholders desire a faster remediation option some time in the future.

- Reinjection of treated water may improve hydraulic control of the plume. If the water were reinjected downgradient of FSUST (i.e., between MW-7 and MW-9), the hydraulic containment would be improved by the presence of the recharge mound at that location. One way to reinject the water would be through the use of a trench functioning as an infiltration gallery, which would provide a larger volume of aquifer through which the water would be recharged relative to wells, although wells could be used too. If necessary, the infiltration gallery/recharge wells could be used for electron donor or other amendments in the future.
- Use of the Ribbon NAPL Sampler (NAPL FLUTE) to confirm presence of NAPL in high concentration source areas could enhance existing characterization data.
- Finally, another option that could enhance the remedy performance is the use of the backfilled gravel pit as a large diameter well for extraction. Of course, this option and the use of the pit for electron donor addition are mutually exclusive. Implementation of this option conceptually might involve drilling the central extraction well through the gravel pit and extending the screen up into the pit to ensure that the entire pit surface is used for extraction. This might result in a slightly higher discharge rate, although once the water were pumped from storage in the pit, the effect might be minimal.

The Stanford Management Company has specifically requested evaluation of enhanced bioremediation as a supplement to the containment strategy. In response to this request, SLAC has sought input from at least two consultants, Erler & Kalinowski, Inc. (EKI) and Geomatrix Consultants, regarding the possible scope, cost, and technical issues associated with evaluating enhanced bioremediation in the field. In light of Stanford's interest in the technology and given the differences of opinion expressed during these scoping exercises, additional discussion of the TAT's recommendations is appropriate.

On August 20, 1999, EKI submitted a potential scope and cost to SLAC for evaluating enhanced bioremediation. This document discusses some of the technical issues associated with evaluating the technology at the FSUST site, and then presents a proposed approach with a schedule and cost estimate. On September 24, 1999, Geomatrix provided comments to the Stanford Management Company on EKI's document with some of their own recommendations. The TAT has reviewed both of these documents. Overall, the EKI "proposal" is thorough and technically sound; however, the scope may be more than is required for the FSUST site, as noted by Geomatrix.

EKI identified three main technical issues: 1) the high sulfate in ground water, 2) inhibition of contaminant degradation by the high concentrations of other contaminants, and 3) delivery of electron donor solutions in the low permeability aquifer. While the first issue is an important consideration because it represents a significant "sink" for added electron donors, data from VP-

1 indicate significant sulfate reduction is already occurring as noted in the Contaminant Fate and Transport subsection of this report (Section III, Subsection A), and by both EKI and Geomatrix. It is notable that this sulfate reduction appears to be occurring without significant production of hydrogen sulfide gas. The second issue may have some effect, but the field data demonstrate that degradation is occurring, so the benefit of investigating this further in the laboratory may be minimal. The third issue is probably the key in determining whether enhanced bioremediation can be effective at the FSUST site and it can only be evaluated in the field. These considerations suggest that laboratory studies would have limited benefit and that the focus should be on the ability to deliver electron donor beneficially in the field, as suggested by Geomatrix.

The scope for a field pilot test proposed by EKI is thorough and well founded, but appears to consider the approach as a stand-alone remediation, as opposed to a supplement to the containment strategy. In the latter case, a much more passive evaluation could be performed. The TAT recommendation is perhaps even more passive than the recommendation of Geomatrix. It does not call for an injection well, and might be able to use VP-1 and one or more of the hydraulic containment wells as monitoring wells. The monitoring should be intermediate between the EKI proposal and the Geomatrix recommendations. While the EKI proposal would be appropriate for a rigorous pilot test of enhanced bioremediation as a stand-alone technology, more limited monitoring would be appropriate in the context of the proposed remedy at FSUST. However, the Geomatrix approach of using oxidation-reduction potential (ORP) alone as an indicator parameter is not recommended. While ORP should be a good indicator in principle, in practice its reliability as a primary indicator is limited. It is best used in conjunction with other measurements that can be made in the field such as dissolved oxygen, ferrous iron, sulfate, chemical oxygen demand, and alkalinity. Monthly measurement of these parameters in the field would probably suffice at the FSUST site, given the operation of the containment system and the slow advective flow. Sampling and analysis of VOCs and ethene/ethane/methane could be performed on a less frequent (perhaps quarterly) basis. The primary goal of the activities recommended for consideration would be to determine if a passive electron donor addition strategy is effective. If the delivery is effective, the site data give every indication bioremediation will be enhanced. The additional cost to evaluate enhanced bioremediation as a supplement to the proposed remedy should be small ($20,000-50,000), minimizing the risk to DOE, while addressing the concerns of the Stanford Management Company and potentially accelerating the cleanup.

These recommendations are provided as suggestions for the enhancement of what is believed to be a technically sound approach to remediating and managing the FSUST site. (Contact Kent Sorenson of the TAT with any questions about the review of the EKI and Geomatrix evaluations or about recommendations for the FSUST in general).

V. PLATING SHOP AREA

A. Critical Issues

Characterization at the Plating Shop Area is much earlier in the investigation phase than the FSUST site. However, like the FSUST site a primary issue is the conceptual model, which would enhance the explanation of contaminant fate and transport at the site. As discussed in detail in section III, development of this model will greatly assist remediation of the site by aiding the design process, facilitating communication with stakeholders, and helping plan for long-term stewardship of the site. The Plating Shop subfloor, an adjacent steam cleaning pad, and the nearby RWTP were identified as potential sources of volatile organic contamination based on a 1997 soil gas survey. Ground water contamination consists of chlorinated organics and was found in the vicinity of all three potential source areas. The highest concentrations were found at MW-21 adjacent to the RWTP. The origin of this contamination is not clear, especially in light of the absence of soil contamination in the area. The Plating Shop and the RWTP have been in operation since 1963. The Plating Shop was constructed with a "wet floor" under most of its area where overflow from chemical rinsing tanks collected and drained to a sump in the subfloor on the east side of the building. Liquids from the sump were piped to the RWTP. In general, it is believed that the liquid rinse spillage was primarily meal plating waste. The RWTP is only designed to treat metal contamination before the effluent is discharged to the SLAC sanitary sewer system. However, spills and leaks from vapor degreasers present in the plating shop would also contribute to liquids in the sump. The steam-cleaning pad was constructed in 1968 and used to clean metal parts that were to be plated as well as other materials. The piping between the Plating Shop sump and RWTP was buried from the sump to the stairs leading down the slope on the south side of the RWTP and followed the pathway. Remedial alternatives are limited in this area because of numerous underground utilities and surface structures.

In 1992, cracks were discovered in the Plating Shop subfloor and a leak was found in the piping connecting the sump to the RWTP, but no evidence of other leaks was noted when old piping was removed and new piping installed. The cracks were sealed and all rinsing tanks were plumbed directly to the RWTP, thereby eliminating the sump and associated piping as a continuing source of contamination. The new piping system was installed in the same location as the older, leaking pipes. Cracks and eroded expansion joints in the steam cleaning pad led to its abandonment in 1997 and a new pad was constructed to the south of it adjacent to the Plating Shop building. A soil gas survey conducted in 1997 identified three suspected areas of VOC contamination in the area: 1) underlying the Plating Shop near the sump, 2) underlying the steam cleaning pad, and 3) underlying and adjacent to the RWTP. Soil samples were collected in each of these areas after the soil survey was completed and revealed VOC contamination only underlying the steam cleaning pad, which was subsequently remediated by soil excavation and offsite disposal. The TAT understands that the soil samples also were analyzed for metals that might be expected in association with plating operations, but these data have not been fully evaluated at this time.

As for the FSUST, the extent of contamination in the PSA is quite limited, extending from very low concentrations only about 100 ft downgradient from the areas with highest concentration. Again, this is consistent with the extremely low conductivity of the siltstone formation. Although the characterization is incomplete, it seems likely that the RWTP contamination has a plume that is separate from the Plating Shop and steam cleaning pad contamination. The latter two source areas likely have commingled plumes.

Twelve monitoring wells exist in the vicinity of the Plating Shop and RWTP that were installed between 1996 and 2000. Most of these wells range from ~25 to 35 ft deep. The single deep well (MW-48) is approximately 78 ft deep. Screens in these wells typically range from 10-20 ft in length. The wells are used for making periodic water level measurements and collecting ground water samples for analysis. When coupled with water level data obtained from monitoring wells elsewhere at SLAC, the potentiometric surface in the vicinity of the Plating Shop clearly defines a southeasterly trending gradient that appears to be greatly influenced by the location of the two trenches for the linear accelerator trench.

Two pumping tests were conducted in this area. In 1997, a 13-hour test was conducted at MW-38 with MW-23 as the primary observation well. MW-38 is a good producing well for SLAC, and a clear head response was noted at MW-23 during the test. The report prepared by SLAC suggests that this may be indicative of fracture flow between the wells, although the TAT are unaware if this interpretation has been confirmed by further testing. The second pumping test was conducted during July 2000 in which MW-21 was pumped for 8 days with MW-64 and MW-48 as the primary observation wells with wells MW-40, 65, 62, 63, 23, and 38 also monitored for drawdown. Very little response was noted in any of the wells, even when taking into account background barometric variations. Monitoring wells 62 and 63 near the Plating Shop, and wells MW-21 and 64 near the RWTP, appear to have significant VOC contamination. The most highly contaminated well is MW-21 where a total VOC concentration in excess of 6 ppm has been reported. The mix of specific VOC contaminants in these and other wells at the site is variable and might point to several different sources of contamination. The ground water analyses review by the TAT did not include information on metal contamination that might have been associated with the Plating Shop. The TAT understands that these data are available, but have not been carefully evaluated yet. The water table at the Plating Shop ranges from around 25 ft near the shop to 10 or 15 ft at the bottom of the hill near the RWTP.

The limited ground water data available for the PSA suggest that biodegradation of the chlorinated organics may be significant. At MW-21, *cis*-1,2-DCE concentrations are nearly equal to TCE concentrations. Very little data regarding redox conditions have been collected to date, so a conclusive determination of biodegradation cannot be made at this time. Further characterization will be required before contaminant transport can be discussed in more detail. It should be noted that the low detection of metals contamination, to date, with the organics in soils and ground water is very surprising for a Plating Shop. Further characterization will determine the degree of metal contamination.

B. Identification of Information Gaps & Uncertainties

Based on review of the information presented at the meeting, the TAT believes that there are several information gaps and key questions that remain to be addressed including:

- What is the distribution of soil and ground water contamination (VOCs and metals) in the area? The TAT believes conclusions regarding the location of contamination source areas in soils and transport pathways in ground water remain open questions that require resolution. In addition, the TAT suspects that soil (and ground water) contaminated with metals may have escaped early detection. Metal plating activities frequently result in release of chromium and other metal contamination to the environment and can be found to impact both soils and ground water.

- Can the observed ground water contamination at the site be correlated with reasonable source areas that might reveal additional zones of soil/ground water contamination? The TAT understands that review and evaluation of historical photographs and process knowledge documented in reports and shop records, along with interviews with long-term employees who worked in the Plating Shop or RWTP, is in progress for this site. As demonstrated at the FHWSA site, this type of information can be very helpful in reconstructing a history of site disposal activities and identifying potential contamination sources.

- Is there some reasonable interim action that can be undertaken to address ground water contamination at MW-21 even as additional evaluation of the site continues?

C. Recommendations

The TAT's understanding of site conditions and data availability for the Plating Shop, steam cleaning pad, and RWTP is based on handouts, oral presentations, and a site tour. These sources of information lead us to a set of recommendations for further work that should help resolve key issues and information gaps. These recommendations are presented below.

- First, the TAT recommends that a record of events taking place at the Plating Shop site should be assembled and evaluated. Information for this record of events can be found in historical photographs and documents, as well as process knowledge gleaned from reports and interviews with long-time employees at the site. Of particular interest will be information concerning what types of solvents were used, when they were used, and where and how they were disposed. This information can be used to target suspect areas for further sampling and evaluation.

- Closely related to the first recommendation is the need to locate and investigate buried former and current process waste transfer lines running from the Plating Shop to the RWTP. The TAT understands that as-built diagrams for the site provide adequate location information. Surface geophysical methods might be employed to confirm the locations if any uncertainty remains. Once located, it is essential to test the bedding and surrounding soil along these lines, particularly in the vicinity of the original piping that is known to have leaked. Pipe and utility bedding material is typically much more permeable than the native soil and can be a significant pathway for contaminant transport.

- Review of information about cracks in the Plating Shop subfloor and sump will provide valuable information about the potential location of additional soil contamination underlying the Plating Shop. Guided by this information, SLAC should take steps to collect soil samples in suspect regions not previously tested and analyze them for the presence of VOCs and metal contamination. More extensive soil sampling in high-priority areas previously sampled might be necessary. These data should be combined with the existing soil data and evaluated for the location of potential source areas. Particular care should be taken to screen for the presence of metal contamination (e.g., Cr), as this is a likely outcome of leaks and spillage associated with a plating facility.

- The TAT noted that a ground water sample and sample split were collected from MW-21 on August 3, 2000 and analyzed by different laboratories. These two analyses differed markedly and non-systematically from one another. However, other samples and their splits reported in the handout for this area generally correlate well. The TAT understands that analysis of samples and their splits by different laboratories is not routine at SLAC and might account for the observed differences. The TAT recommends a review of QA/QC procedures take place to help resolve the issue. VOCs are highly susceptible to evaporative losses and care must be taken in sample collection and handling to avoid this problem. Regardless, the differences observed are substantial, and steps should be taken to resolve this issue.

- The TAT recommends that SLAC consider evaluating the chemical fingerprints of ground water samples in this area in an attempt to identify connections between different wells and potential source areas. For example, examination of the contaminant chemistry from nine wells reported in the handout the TAT received shows that MW-62, 63, and 64 all share some unique features in common. These are the only wells in this area where chloroform, 1,4-dioxane and Freon 113 are reported. In addition, MW-63 and 64 are the only wells in the area where trichlorfluoromethane is reported. MW-62 and 63 are adjacent to the Plating Shop while MW-64 is close to the RWTP and located only about 20 ft from MW-21, to which it bears little chemical similarity. Other factors may explain some of these differences, but identifying unique chemical signatures in ground water samples can help in the reconstruction of contaminant transport pathways.

- Chemical fingerprinting need not be restricted to contaminant constituents. Use of distinctive ratios of major cations, anions, or isotopic species (e.g., C, H, O) also can help map ground water flow pathways. The TAT recommends that consideration be given to applying these methods in this area, if possible.

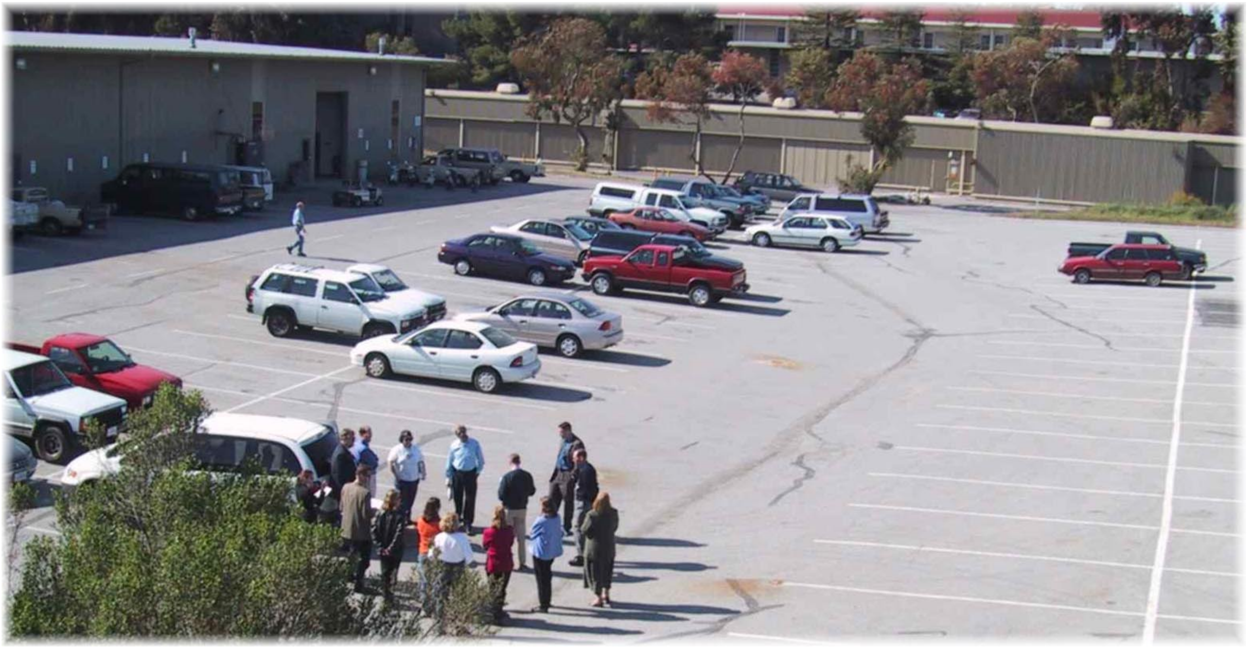
- Another recommendation involves collection of dissolved gas data from selected ground water samples. Specifically, it is desirable for SLAC to collect dissolved gases for CH_4, CO_2, O_2, ethene and ethane analysis. Evaluation of the presence of these gases will help confirm existence of natural biodegradation processes and the redox state of the ground water system.

- As data are collected and analyzed for this area, the TAT strongly encourages SLAC to integrate the results into the site conceptual model to confirm the applicability of that model or to refine it as appropriate. There are likely to be site-specific differences in the PSA in comparison to the other sites considered in this report that will be a function of local, unique features (e.g., ground water flow direction, lithologic variations, etc.).

However, the importance of demonstrating that this site fits into the conceptual framework for the entire SLAC site cannot be underestimated.

- As a final recommendation, the TAT suggests a possible interim action to address the region of greatest apparent ground water contamination in the vicinity of MW-21. The TAT suggests that SLAC may find it useful to begin pumping this well and treating the effluent either in a small, dedicated well-head treatment module, or by discharging it directly to the RWTP. Examples of dedicated treatment systems have been developed by Lawrence Livermore National Laboratory (LLNL) and are available as portable units of several different sizes depending upon need. Information about these treatment units is available from Ed Folsom, the Engineering Group Leader at LLNL (Phone: 925-422-0389). If direct discharge of effluent to the RWTP is the option selected, it may be necessary to add a small treatment module (e.g., GAC) to the RWTP treatment system.

VI. FORMER HAZARDOUS WASTE STORAGE AREA



A. Critical Issues & Information Gaps

The Former Hazardous Waste Storage Area is located on the southern side of the LINAC near the southern boundary of the SLAC property. This site was used as a waste storage area from the early 1970's to the early 1980's. Liquid solvent wastes were stored directly on the ground, primarily in 55-gallon drums. Approximate storage locations over the duration of the operation have been delineated from examination of aerial photos. Significant staining of the ground was observed in those aerial photos. It has not been possible to estimate spill volumes, but given the nature of the operation, contaminant source areas probably have been derived from small individual spills and leaks. However, no specific point sources have been identified. Like the other two sites, the primary issue is the conceptual model, which would enhance the explanation of contaminant fate and transport at the site. As discussed in detail in section III, development of this model will greatly assist remediation of the site by aiding the design process, facilitating communication with stakeholders, and helping plan for long-term stewardship of the site.

The site is generally flat, sloping slightly from the northwest to southeast and is currently covered with an asphalt parking lot. A storm drain runs north to south down the center of the site. There appear to be two separate plumes, a predominantly 1,1-DCE plume in the northwest corner of the site, and a predominantly PCE plume in the southern portion of the site. 1,4-dioxane occurs in the central and southern portion of the site. The subsurface was characterized by using soil gas measurements above the water table, soil borings above and beneath the water table, and ground water sampling from monitoring wells. Building 15, which is at the west end of the site, appears to lie over a portion of the northern plume.

It is unclear whether infiltrating solvents moving as a DNAPL have reached the shallow water table, approximately 15 feet below land surface at the center of the site and 20 ft at the north end of the site. Small spill volumes argue against deep infiltration. DNAPL is more likely to have reached the water table in the northern plume near the northeast corner of Building 15 where ground water concentrations are highest. Ground water concentrations in the several parts per million range in MW-66 suggest that separate phase organics may exist somewhere proximal to the water table at this location. Due to poor permeability, it is not likely that any DNAPL reaching the water table would be able to continue to migrate downward beneath the water table.

Ground water sampling has been more limited than the vadose zone sampling performed to date. The results obtained thus far mirror the soil gas data. High concentrations of volatile organics on the order of 1,000 μg/L have been found, especially consisting of PCE near the southern hot spot and 1,1-DCE near the northern hot spot. Based primarily on MW-49, the contamination appears to be limited to shallow ground water. A possible explanation for the distribution of the contamination in the soil column (which is present in soil gas, minimal in the soils, present in shallow ground water, and absent in deeper ground water) is that the contamination is largely contained in the capillary fringe. If small quantities of nonaqueous contaminants reached the capillary fringe following leaks or spills, they likely would not have had sufficient mass to exceed the high entry pressures of the water-saturated siltstone and would have stopped migrating vertically at that point. It has also been suggested that the contact between the Santa Clara and Ladera formations might be preventing vertical spreading, but this appears to be speculative and it is not clear what would cause this effect.

Although migration of the contaminants appears to be limited as for the other two sites, current monitoring well locations do not allow this to be confirmed. The hydraulic gradient seems to be oriented to the east northeast at the center of the site and southeast of the southern hot spot, and is close to due north near the northern hot spot, strongly influenced by the presence of the LINAC drain trench. Unfortunately, the area immediately downgradient of the southern high concentrations in MW-58, MW-50, and MW-25 currently has no monitoring wells. While MW-43 might be downgradient of MW-66, the most contaminated northern well, no other monitoring wells are north of MW-66 to confirm the size of the contaminated area. Even considering the slow transport rates expected in this hydrogeology, the proximity of the contamination in MW-66 to the LINAC drain trench merits further investigation.

Once in the subsurface, the spilled solvents can volatilize and travel through the gas phase by diffusion and advection. Volatilized organics can form a dense vapor that can sink through the formation. Also barometric pressure fluctuations can cause soil gas movement. VOCs partition between the gas and the aqueous phase, striving to reach equilibrium between the phases according to Henry’s Law. As VOC laden soil gas migrates, it contaminates the soil water and ground water it encounters along the way. The continuous nature of the VOC contours as constructed from the soil gas surveys indicate that gas phase migration probably provides a significant component of the migration above the water table. The soil gas surveys also indicate that the vast majority of mass remaining in the subsurface remains in the vadose zone above the water table. Given the small spill volumes and the fine texture of the formation, it is not likely that sufficient pressures could be generated to overcome the capillary pressures that resist penetration of DNAPL beneath the water table.

Ground water has been contaminated at the site. Prior to construction of the LINAC, ground water flow followed the topography moving to the south and east towards San Francisquito Creek. The southern plume resides on this flow path. Assuming insufficient attenuation and given enough time, there is potential for contaminants to eventually leave the site property and ultimately discharge into San Francisquito Creek. However, considering dilution and the extremely slow migration rates it is unlikely that this will ever occur. North of the site, construction of the LINAC lowered the water table. Ground water contours indicate that flow from the northern portion of the site is northward toward the LINAC. Again, given enough time along with insufficient attenuation, contaminants from the north portion of the site could eventually discharge into the subdrainage beneath the LINAC and ultimately into San Francisquito Creek. Again given the very slow migration rates, dilution and volatilization it is unlikely that contaminants will reach the LINAC.

Like the other sites at the SLAC, ground water flow is slow. Over most of the site, where ground water appears to be moving to the east and southeast, velocities are calculated to be on the order of one ft per year or less. At the northern portion of the site, where ground water contours appear to be closer, the velocities could be as much as three to five times higher. Given these low ground water flow velocities, gas phase migration from source areas with contaminant partitioning into the ground water may prove to be the more important mechanism for evolution of the ground water plumes over time.

Due to the lack of data on redox conditions at the FHWSA, it is difficult to assess degradation at the site. The presence of significant amounts of PCE in the southern hot spot suggests that reductive dechlorination is not significant for that portion of the site. This is most likely due to a lack of oxidizable organic material. The high concentrations of 1,1-DCE in the northern hot spot could be due to the disposal of this compound as an original waste, or due to the abiotic degradation of TCE. Detailed breakdowns of the contaminant data was not available to review for the FHWSA, making further evaluation of the importance of degradation infeasible. This information could facilitate an improved assessment of the possibility of reductive dechlorination, but further data would be needed to confirm this preliminary assessment.

B. Recommendations

Given the TAT's understanding of the key issues surrounding selection of a remedial option for the FHWSA ground water plume, and the characterization data gaps that exist for the site, the TAT suggests the following recommendations:

- Additional wells are needed to better understand the maximum extent of the two plumes. Additional assurance that contaminated ground water is not migrating offsite will allow for low-budget, long-term passive remediation at the site.

- Specifically, the TAT recommends one additional monitoring well to better characterize the southern plume to be located between MW-33 and MW-59, and one additional monitoring well to better characterize the northern plume to be located north of MW-66 by the LINAC.

- As these monitoring wells (and any additional boreholes) are installed, the TAT recommends field screening for VOCs to help determine subsurface locations having high concentrations that may signify the presence of DNAPL. This is especially important beneath the water table to help verify that DNAPLs have not penetrated into the aquifer.

- Aside from the field screening for VOCs, no additional vadose zone characterization is required. Vadose zone characterization to date and analysis of the site history have been excellent to date. Although specific localized source areas have not been identified, additional characterization is not likely to yield results without excessive expenditures. In addition, since contamination may be primarily limited to the vadose zone, explicit delineation of source areas is not required to institute passive remediation.

- The TAT recommends passive venting as a possible interim remedial action for this site. Removing the asphalt parking lot and replacing it with gravel is one possibility to facilitate VOC removal by encouraging diffusive transport and barometric pumping. Alternatively, landscaping strips that include grass and trees could divide rows of parking spaces. This would also provide an avenue for soil gas to vent. Installation of “Baroballs” (passive soil vents) in these strips would enhance barometric pumping. Also the trees planted in these landscaping strips would allow for transpiration by the trees to remove contaminated water, while perhaps also providing some measure of hydraulic control.

- This site could serve as a location for pilot studies to support activities at the other two sites, if desired. Since this site is not as encumbered by buildings and utilities, it provides a location to test remedial activities to be implemented at the other sites with minimal disruption for SLAC workers.

VII. SUMMARY & CONCLUSIONS

The SLAC environmental project leaders provided a good overview of the three sites and the strategies being developed for each site. It was clear that this small group of highly dedicated and knowledgeable geologists and engineers are making an excellent effort in characterizing and remediating their site, especially in light of the limited budget available. Their understanding was especially apparent during the site tour. The TAT believes that it received, in the short time available, a reasonable appreciation of the issues concerning the environmental characteristics of the site, public perception, and the regulatory drivers. The TAT uniformly agrees that the SLAC project leaders' efforts to understand the site have, thus far, led to sound remedial action decisions, and have provided DOE with excellent resource management and stewardship of their site. The TAT made several recommendations that should help them improve communication to the stakeholders and regulators. In addition, the TAT made specific recommendations to help improve remediation performance at the FSUST site, and help further characterize, monitor, and eventually make remedial decisions at the PSA and FHWSA site. Development of a site-wide conceptual model is the TAT's strongest recommendation to the site. The TAT believes that this model will become integral to their communication with the regulators and stakeholders and will ultimately contribute significantly to long-term stewardship of the site.

VIII. REFERENCES

Groundwater Currents, December 2000, Issue 38 (see EPA CLU-IN web site) http://www.wpi.org/initiatives/init/summer00/bioremediate.htm

SLAC, 1998, Draft Site Characterization of the Former Solvent Underground Storage Tank Area, SLAC-1-750-3A-33H-005

The "Innovative DNAPL Characterization Technologies" website contains information about the Ribbon NAPL sampler (http:www.envnet.org/scfa/prodlines/factsheets.htm)

Ed Folsom, Engineering Group Leader at LLNL, can provide information about dedicated treatment units (Phone: 925-422-0389)

APPENDIX A LIST OF ATTENDEES

SIGN-IN SHEET
SCFA LEAD LAB TECHNICAL ASSISTANCE EFFORT AT SLAC
APRIL 5-6, 2001

Last	First	Affiliation	Phone	E-mail Address
Conrad	Steve	SNL	505-844-5267	shconra@sandia.gov
DeCamera	Micki	SLAC	650-926-2348	mdecamera@slac.stanford.edu
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Kase	Ken	Division Director	650-926-2045	kkase@slac.stanford.edu

APPENDIX B TECHNICAL ASSISTANCE REQUEST

Tracking Number:	82
Request Title:	VOCs in SLAC Contaminants Plume
Contact Individual:	Jay Tomlin
Requesting Organization:	U.S. DOE – Oakland Operations Office
E-Mail Address:	jay.tomlin@oak.doe.gov
Phone Number:	(510) 637-1637
Fax Number:	(510) 637-2031

Scope of Work:

On the site of the Stanford Linear Accelerator Center there is a solvent plume that originated from a leaking waste solvent storage tank in which a wide variety of waste solvents were stored. Comprehensive characterization has shown that the plume is restricted to an area of approximately 1-acre. The ground water level begins about 5 feet below the ground surface. Contamination reaches to a depth of approximately 30 feet below the ground surface. The principal contaminants are acetone, ethylbenzene, toluene, xylenes, methyl chloride, 1,1,1-trichloroethane, and trichloroethylene. Geologic investigations confirm that the surface is underlayed with hard rock interspersed with fracture zones. The water quality of the naturally occurring water is poor with sulfate levels to 4,000 mg/L. The site would like to have recommendations on how to maintain plume control and a cost-effective methodology for destroying the contaminants to acceptable levels. The current baseline is pump and treat for the foreseeable future with an operation and maintenance cost of approximately $146,000 to $163,000/year. There are one or two other solvent plumes on site that could also benefit from the requested recommendation.

Support:

What resource(s) have been selected?

What resources were offered, but not selected?

Requested Start Date:	**2/1/01**	**Requested Completion Date:**	**4/2/01**
Estimated Cost:			

Submitted By: Jay Tomlin______________________

APPENDIX C TECHNICAL ASSISTANCE TEAM

STEVE CONRAD

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Education:
- Ph.D. in Hydrology, New Mexico Institute of Mining and Technology (1991).

Areas of Expertise:
- Hydrology
- Probabilistic performance assessments for radioactive waste disposal
- Systems analysis

THOMAS O. EARLY

Senior Development Staff member
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P.O. Box 2008, Oak Ridge, Tennessee 37831-6038
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Education:
- Ph.D. in Geochemistry; Washington University, St. Louis, MO (1971)

Areas of Expertise:
- Hydrogeochemistry
- Environmental impacts to groundwater of past waste disposal practices
- Innovative technologies for remediation of chlorinated solvents in the subsurface

CAROL EDDY-DILEK

Principal Scientist
Westinghouse Savannah River Company, Savannah River Technology Center
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Education:
- M.S. in Geology, University of California, Davis, California (1985)

Areas of Expertise:
- Environmental Site Characterization
- Development and Deployment of Environmental Sensors and Systems
- DNAPL Site Characterization

TERRY HAZEN

Head, Environmental Remediation Technology Program
Head, Microbial Ecology & Environmental Engineering Department
Director, Center for Environmental Biotechnology
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Education:
- Ph.D. in Microbial Ecology, Wake Forest University, Winston-Salem, North Carolina (1978)

Areas of Expertise:
- Bioremediation (In Situ and Ex Situ)
- In Situ Remediation
- Water Quality

FREDRIC HOFFMAN

Hydrogeology Group Leader, Environmental Restoration Division
P.O. Box 808, L-530, Lawrence Livermore National laboratory, Livermore, CA
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Education:
- Advanced Graduate Studies, Hydrogeology, Feinberg Graduate School, Weizmann Institute of Science, Rehovot, Israel (1995)

Areas of Expertise:
- Subsurface characterization and ground water remediation design and implementation
- Investigation and remediation of ground water contaminated with solvents

KENT S. SORENSON, JR.

Principal Engineer
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Education:
- Ph.D. in Civil and Environmental Engineering, University of Idaho, Moscow, ID (2000)

Areas of Expertise:
- Intrinsic and enhanced biodegradation of chlorinated solvents in a deep, fractured rock aquifer, including hydogeologic characterization

GUS WILLIAMS

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Education:

- Ph.D. in Environmental Geotechnology; Minor in Engineering Project Management
  Northwestern University, Evanston, Illinois

Areas of Expertise:

- Computer simulation of subsurface contaminant fate and transport
- Scientific visualization
- Subsurface remedy assessment

APPENDIX D PICTURES

TABLE 1 FORMER UNDERGROUND STORAGE TANK MAP